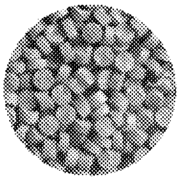


Processing and End Markets

- **Opportunities for reprocessing of multi-material flexible packaging (MMFP) are limited.** Reprocessing in general refers to operations that aim to recover sorted plastics received from MRFs via mechanical processes (i.e. grinding, washing, separating, drying, re-granulating and compounding) and production of recycled plastic flakes or pellets that can be reused to make new products. The technical capability does exist to reprocess polymers in polyolefin based multi-material flexible packaging, however there are also many limitations. Limitations are often caused by the different melting points of different polymers, which makes it challenging to get quality output from mixed polymers. It is generally considered important to know what the incoming resin composition is and keep it consistent and relatively clean so that equipment can be adjusted accordingly to get the best outputs based on the unique qualities of the incoming polymer mix. This makes it highly challenging to use multi-material flexible packaging collected at the curbside where much of this information is unknown and unpredictable.

- **Most existing processes can typically use only a small percentage of MMFP**, due to this variability of input, so MMFP represents a small percentage of the composition of the product produced (see example end markets from mixed flexible packaging on page 26 of the [HYPERLINK "https://www.materialsrecoveryforthefuture.com/wp-content/uploads/MRFF-Pilot-Report-2020-Final.pdf" \h]). New technologies like compatibilizers (described above) and [HYPERLINK "https://x2f.com/" \h] for processing plastics with different melting points are emerging that might address some of these limitations.

- **New technologies are emerging that use chemical and water-based solvents to dissolve bonds between layers, separating them**. These processes can be added onto existing mechanical recycling processes and can expand the markets to those of distinct polymers, rather than send the package to a mixed flexible plastics bale that could potentially be destined for less preferable forms of recovery like waste-to-energy. These technologies are very promising additions to the capabilities of mechanical recycling for MMFP, however have yet to be applied at scale. Often these technologies require pure streams of specific laminated packaging types, as different solvents work to separate different combinations of layers (i.e. PET/PET), and one solvent may not work for all varieties of MMFP in mixed plastics bales.

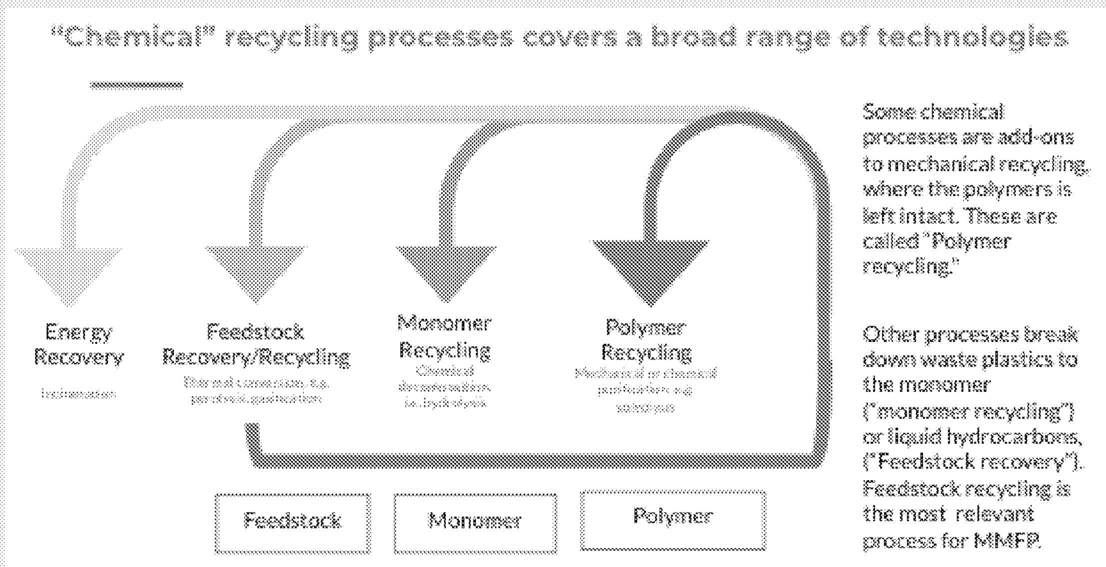
[HYPERLINK "https://docs.google.com/document/d/1GgMF52RzaGlvx9alqjhfH6oMvtMgvnCANDbx3A2V7dM/edit" \h][HYPERLINK "https://sustainablepackaging.org/multi-material-flexible-recovery-mechanical-recycling/" \h]

- Reprocessing options for multi-material flexible packaging includes more than just mechanical recycling. **For multi-material flexible packaging, so-called "Feedstock Recycling" technologies which reconstitute plastic films to more basic hydrocarbons is an opportunity area for multi-material film recovery**. Feedstock recycling is achieved by heating the plastic at high temperatures in a chamber that is either void of oxygen (pyrolysis) or uses oxygen and steam (gasification), with many variations of these processes being developed. These processes simulate virgin feedstocks for plastics (e.g. oil and gas), and from these hydrocarbon outputs, a variety of end products may be created that have virgin-like properties. These outputs include many of the chemicals, plastics, waxes and other products made from virgin fossil fuel feedstocks today. The output can also be used in fuel applications.

- Exploration by the Multi-Material Flexibles Recovery Collaborative **suggests that feedstock recycling may be one of the most viable options currently available for the end of life management of multi-material flexible packaging**. Unlike other plastics like rigid PET or mono-material PE, MMFP cannot be viably recycled mechanically. However, most of these recovery technologies are still in the pilot stage and the economics of the market are still emerging, with markets currently in favor of fuels instead of plastics end markets. As sortation and collection of significant volumes is still a challenge, the processing of multi-material flexible packaging only is unlikely to produce sufficient volume, additional plastics to supplement processing demand is likely. So instead, mixed plastic waste inputs are preferred.

Clarifying terms

"Chemical" recycling processes cover a broad range of technologies, including chemical purification during Polymer Recycling (i.e. using chemicals in mechanical recycling), Monomer recycling via chemical depolymerization which breaks apart polymers into individual monomers through processes such as hydrolysis (which does not generally apply to polyolefins), and Feedstock Recycling technologies, which reconstitute plastics to more basic hydrocarbons.



The term *Feedstock Recovery* is used to broadly cover all of these outputs of these processes. It can be called *Feedstock Recycling* when its outputs are put towards non-fuel use, per [HYPERLINK "https://www.iso.org/obp/ui/" \l "iso:std:iso:18604:ed-1:v1:en"]which state "Material Recycling is defined as reprocessing, by means of a manufacturing process, of a used packaging material into a product, a component incorporated into a product, or a secondary (recycled) raw material, excluding energy recovery and the use of the product as a fuel." Polymer manufacturers can use this output as feedstock to produce new products.

There is a hierarchy of preference for these technologies based on environmental footprint and end products. Feedstock-to-plastics are preferred to fuel outputs;

however, there is still a place for non-plastic feedstocks in bridging the gap for flexible packaging recovery until plastics-to-plastics markets are scaled up.

- Waste-to-energy (WTE) is the process of generating energy in the form of electricity and/or heat from the combustion of mixed waste, including multi-material flexible packaging left for disposal. While waste-to-energy is a commonly accepted practice in many European countries, it is less popular in North America. However, it still represents a significant end market for MMFP in North America. **As seen in our Technology Recovery Map, incineration represents the largest end market for pre-consumer MMFP waste**, for example, used by cement kilns who burn and use this for energy. Another popular end market was for use as engineered fuel pellets, which are also set to be burned for energy/fuel.

- **Currently, there are no large scale operations available to create end products from multi-material flexible packaging**. While some pilots offer promise, further research estimating and understanding end markets for multi-material packaging would help develop interest and funding for end market development. Materials Recovery for the Future has started this process but more research is needed. One reason much of the current end markets are represented by fuel or energy is due to a lack of robust, alternative end markets.

Planning for the recovery system of the future

Our findings from reviewing existing initiatives and our own projects suggest that there is a future for the recovery of multi-material flexible packaging through some mechanical and chemical recycling processes, and also composting. However, all of these options require significantly more investment, research and innovation to scale.

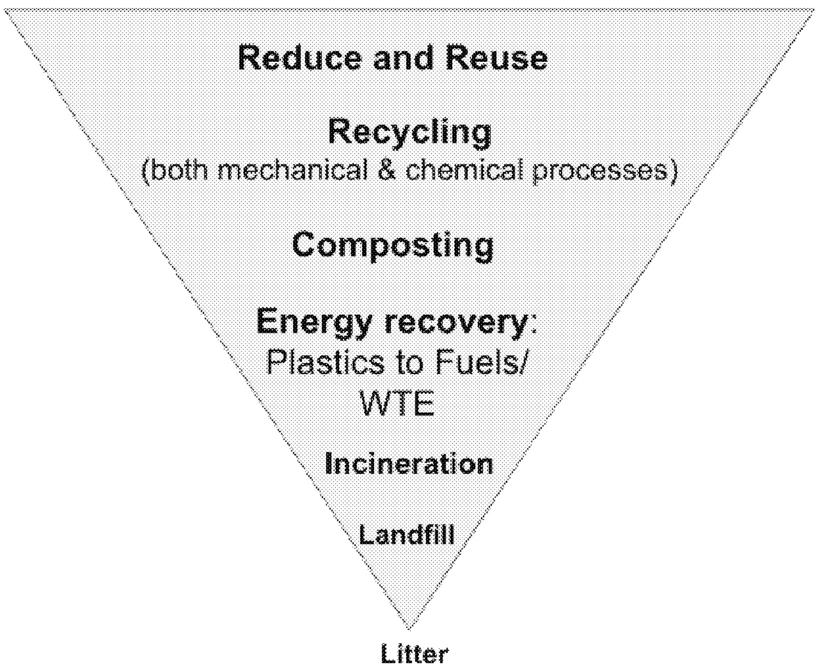
Prioritizing strategies for MMFP Recovery

“Recovery” is an all-encompassing term for a wide range of re-processing technologies that use waste materials to create various new products or resources.

The underlying principles inherent to the Waste Hierarchy offer a general philosophical approach to best and better recovery. The most preferable recovery process:

- Retains maximum amounts of the embodied economic and environmental investment within the feedstock material
- Is socially just, economically productive, and incurs minimal environmental impacts.
- Creates products or resources that directly offset the use of conventional industrial inputs (such as virgin petroleum), creating an overall circular system that is sustainable and regenerative.

The waste hierarchy



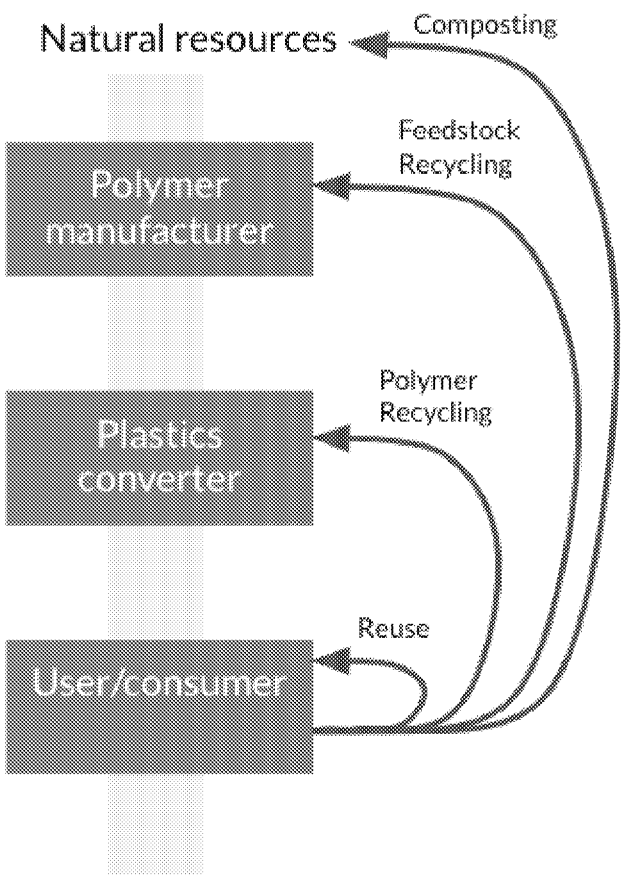
Following Reduction and Reuse, the most preferable forms of recovery are Recycling (including both chemical and mechanical processes that meet [HYPERLINK "https://www.iso.org/obp/ui/" \l "iso:std:iso:18604:ed-1:v1:en" \h]for recycling), Composting, and Energy Recovery processes where plastics are either used as fuels or energy is used for heat/generating electricity , Incineration where energy is not recovered, Landfill, and finally Litter or unmanaged waste. Producers of MMFP should prioritize their recovery efforts accordingly.

1. **Reuse materials** - Wherever possible, explore and innovate new reusable packaging models.
2. **Design for mechanical recycling** - Wherever possible, explore mono-material designs that are more widely recyclable in today's existing mechanical recycling

infrastructure and can be collected through existing store-drop off programs and curbside programs in some places. Best practices for light use of barriers in mono-material packaging can be found in CEFLEX's [HYPERLINK "https://ceflex.eu/" \h] and The Association of Plastic Recyclers' [HYPERLINK "https://plasticsrecycling.org/apr-design-guide/apr-design-guide-home" \h].

3. **Help enable the growth of chemical recycling processes** - When performance needs require the use of multi-material flexible packaging, then mechanical recycling on its own is not likely viable for the breadth of flexible packaging designs/material combinations. Investing in pilot projects and testing new processes that can increase the viability of recycling of these materials is required to scale these technologies. This includes both polymer recycling through use of chemical purification and feedstock recycling for MMFP.
4. **When relevant to the products, invest in composting infrastructure**- Compostable packaging is a good solution for specific types of MMFP that are food packaging and may be soiled, thereby limiting prospects for recycling. If putting compostable material onto the market, it is advisable to also invest in developing collection infrastructure to manage those materials, enabling them to be effectively composted.
5. **Build bridges with other recovery** - The end use of plastics as fuels or energy are seen in general as a less desirable recovery option for MMFP, as the ability to continuously re-use materials is eliminated when material is burned as fuel or energy. However, there is still a place for these outputs in bridging the gap for flexible packaging recovery, especially in the context of Feedstock Recovery, as a replacement for virgin inputs and until plastics-to-plastics markets are scaled up.

Another way to look at the relationship between these recovery options is in terms of different loops in the circular economy. MMFP can fit into the circular economy through an inner loop of reuse of the package, a middle loop of polymer recycling, an outer-middle loop of feedstock recycling, and an outer loop of composting, which brings the materials back to the raw elements of nature. All of these represent opportunities for MMFP in the circular economy.



Long term viability of these different recovery options will be dependent upon the development of viable end markets. Most of the existing efforts to-date that we evaluated increased our understanding of best practices in collection and sortation for mechanical reprocessing (i.e. polymer recycling), but significantly more work needs to be invested into developing economically viable end markets. Once a robust revenue source is established for post-consumer multi-material flexible packaging, it will be easier to justify the investments required to drive further collection and sortation.

Products and packaging do not need to be put back into exactly the same products they came from. In fact, a variety of diverse end markets is desirable from an economic perspective to scale up recovery incentives for these materials.

Feedstock recycling technologies are going to be necessary to address recovery/recycling of multilayer flexible packaging by expanding possibilities for end markets.

Feedstock recycling:

- Produces virgin-like plastic from mixed plastic waste that currently cannot be recycled. This addresses limits with the quality of recycled content currently available on the market via mechanical recycling and creates new markets for these materials;

- Potentially solves issues around food safety and FDA compliance for recycled contact;
- Complements mechanical recycling, providing recycling options for mixed plastic waste while not cannibalizing existing recycling streams and markets;
- Needs more collaboration on pilots across the value chain to scale these technologies;
- Drives economic growth by adding jobs to the system and new areas of expertise and technical know-how;
- Helps maintain the social license to use these materials, enabling the continuation of environmental benefits of flexible packaging like material efficiency and lower emissions profiles compared to rigids, as well as a key role in avoiding food waste.

There are some additional important points that must be taken into account:

- **A pathway to collection of all flexible packaging is essential to scale feedstock recycling.** There is a lack of collection for mixed plastics and flexibles, and it is critical to establish pathways for collection that will eventually serve to supply feedstock recycling.
- **There is a need to better understand environmental impacts** - There has been research by groups like [HYPERLINK "https://www.cedelft.eu/en/publications/2173/exploratory-study-on-chemical-recycling-update-2019" \h] and [HYPERLINK "https://www.basf.com/global/documents/en/sustainability/we-drive-sustainable-solutions/LCA%20ChemCycling_Slide%20deck_final.pdf" \h] suggesting that feedstock recycling is similar in impact to polymer recycling, however there is a need for further research to better understand nuances related to carbon footprint and toxicity impacts of various technologies and end market applications. We also recognize that LCAs will change as our energy mix evolves to be more renewable.
- **It is critical to track materials to their final outputs**. This is key in determining if something is being upcycled, downcycled and to create credibility and accountability in the marketplace when making claims and communicating with consumers and other stakeholders. GreenBlue's [HYPERLINK "https://sustainablepackaging.org/projects/recycled-material-standard-rms/" \h] is working to establish this process.
- **Feedstock recycling is a medium to long term solution** and transition

occurring in industry. It is [HYPERLINK "https://bioplasticsnews.com/2020/06/19/chemically-recycled-packaging-basf-sabicet/" \h] in Europe and has [HYPERLINK "https://www.nexusfuels.com/shell-announces-nexus-partnership-offtake-agreement-and-circular-recycling-strategy/"]projects in place in the U.S. We need additional efforts to support scale these technologies in North America, however, such as pilot projects, scaling of existing pilots, tracking/tracing, investment and supportive policies.

- **Feedstock recycling is not a silver bullet**. Industry also needs to design for mechanical recycling when possible and explore refill/reuse and composting options.

This group will continue to track and explore ways we can support the development of these technologies and packaging to accommodate them in a way that is environmentally responsible.